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Chapter 14

Gear Lubrication

Gears are one of man's oldest mechanical devices. In the public mind, gears are one of the most well recognized kinds of machinery. They create the impression of positive action, coordinated-interlocked-precise application of effort to secure a desired result. The primary early uses of gears were for navigation, timekeeping, grinding, etc. The automobile transmission is probably the most common use of gearing for the everyday citizen.

Gears are machine elements that transmit motion by means of successively engaging teeth (Figures 14-1 and 14-2). Of two gears that run together, the one with the larger number of teeth is called the gear. A pinion is a gear with the smaller number of teeth. A rack is a gear with teeth spaced along a straight line and suitable for straight-line motion. Many kinds of gear teeth are in general use. For each application, the selection will vary depending on the factors involved. One basic rule is that to transmit the same power, more torque is required as speed is reduced. The torque is directly proportional to speed and therefore the input and output torque for power transmissions are directly proportional to the ratio.

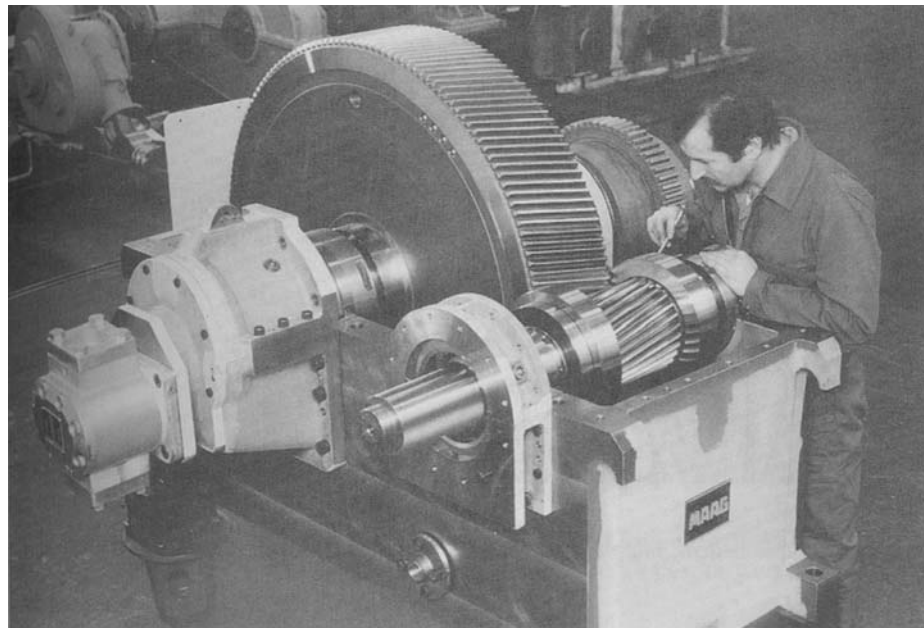

Figure 14-1. Single-helical, high-speed gear unit being assembled. (Source: Maag Gear Company, Zurich, Switzerland)

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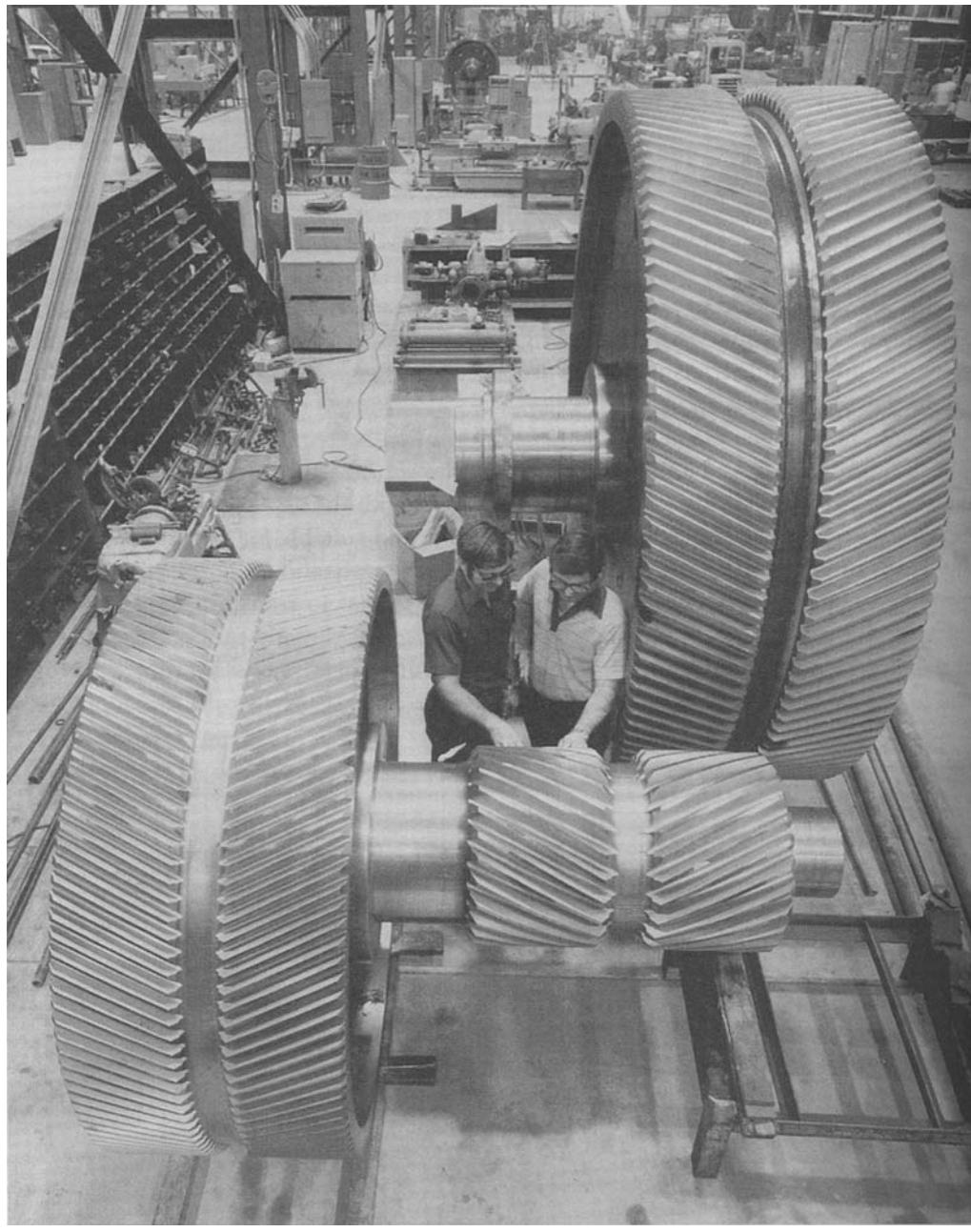

Figure 14-2. Double-helical, low-speed gear unit being checked at Lufkin Gear Company, Lufkin, Texas.

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The gear designer must do more than just provide a mechanism that will develop the required speeds. He must make sure that his mechanism does not break or wear out prematurely because of the power being transmitted. Needless to say, gears must be lubricated.

LUBRICANT SELECTION FOR CLOSED GEARS*

Closed gears are used in many different arrangements, Figures 14-3 and 14-4. The factors affecting lubricant selection for the various arrangements are shown below and should be reviewed and evaluated to determine the required properties.

Factor	Lubricant Properties
Load	Viscosity EP Additives
Speed	Viscosity EP Additives
Temperature (Operating and Ambient)	Viscosity Viscosity Index Fluidity Oxidation Stability
Contamination	Demulsibility Corrosion Protection Oxidation Stability
Life	Oxidation Stability Additive Depletion
Compatibility	Synthetic (Paint and Seals) EP Additives

Also, Tables 14-1 and 14-2 taken from AGMA 250.04 show recommended viscosity ranges based on gear center distance. These recommendations should be used with caution since they are very loosely written.

Viscosity is probably the single most important factor in lubricant selection and relates to load, speed, and temperature.

Table 14-3 is a general guide based on the required viscosity in relation to the Operating "K" factor of the gears and pitch line speed. However, required viscosities can also be calculated from two empirical expressions:

*James R. Partridge, Lufkin Industries, Lufkin, Texas; also Exxon Company, USA, Houston, Texas.

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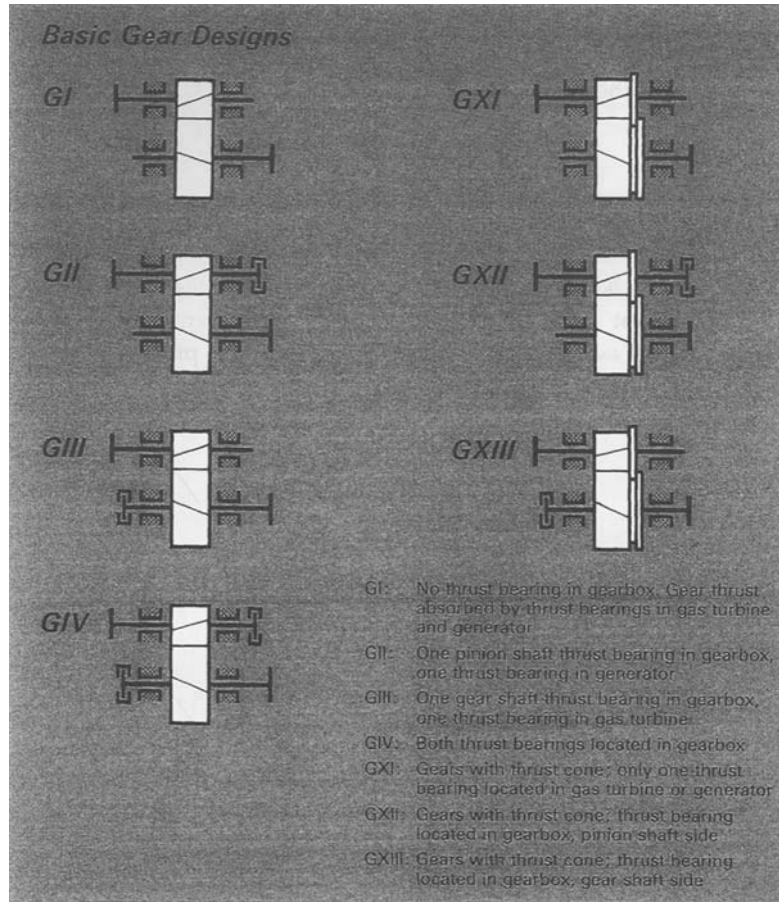
Basic Gear Designs
GI
GII
GIII
GIV
GXI
GXII
GXIII
GI: No thrust bearing in gearbox. Gear thrust absorbed by thrust bearings in gas turbine and generator
GII: One pinion shaft thrust bearing in gearbox, one thrust bearing in generator
GIII: One gear shaft thrust bearing in gearbox, one thrust bearing in gas turbine
GIV: Both thrust bearings located in gearbox
GXI: Gears with thrust cone; only one thrust bearing located in gas turbine or generator
GXII: Gears with thrust cone; thrust bearing located in gearbox, pinion shaft side
GXIII: Gears with thrust cone; thrust bearing located in gearbox, gear shaft side

Figure 14-3. Basic gear designs. (Source: Maag Gear Company, Zurich, Switzerland)

Table 14-1. Viscosity ranges for AGMA lubricants.

Rust and Oxidation Inhibited Gear Oils	Viscosity Range ASTM System	Extreme Pressure Gear Lubricants	
AGMA Lubricant No.	SSU @ 100°F.	AGMA Lubricant No.	
1		193 to 235	
2		284 to 347	2 EP
3		417 to 510	3 EP
4		626 to 765	4 EP
5		918 to 1122	5 EP
6	1335 to 1632	6 EP	
7 comp.	1919 to 2346	7 EP	
8 comp.	2837 to 3467	8 EP	
8A comp.	4171 to 5098		

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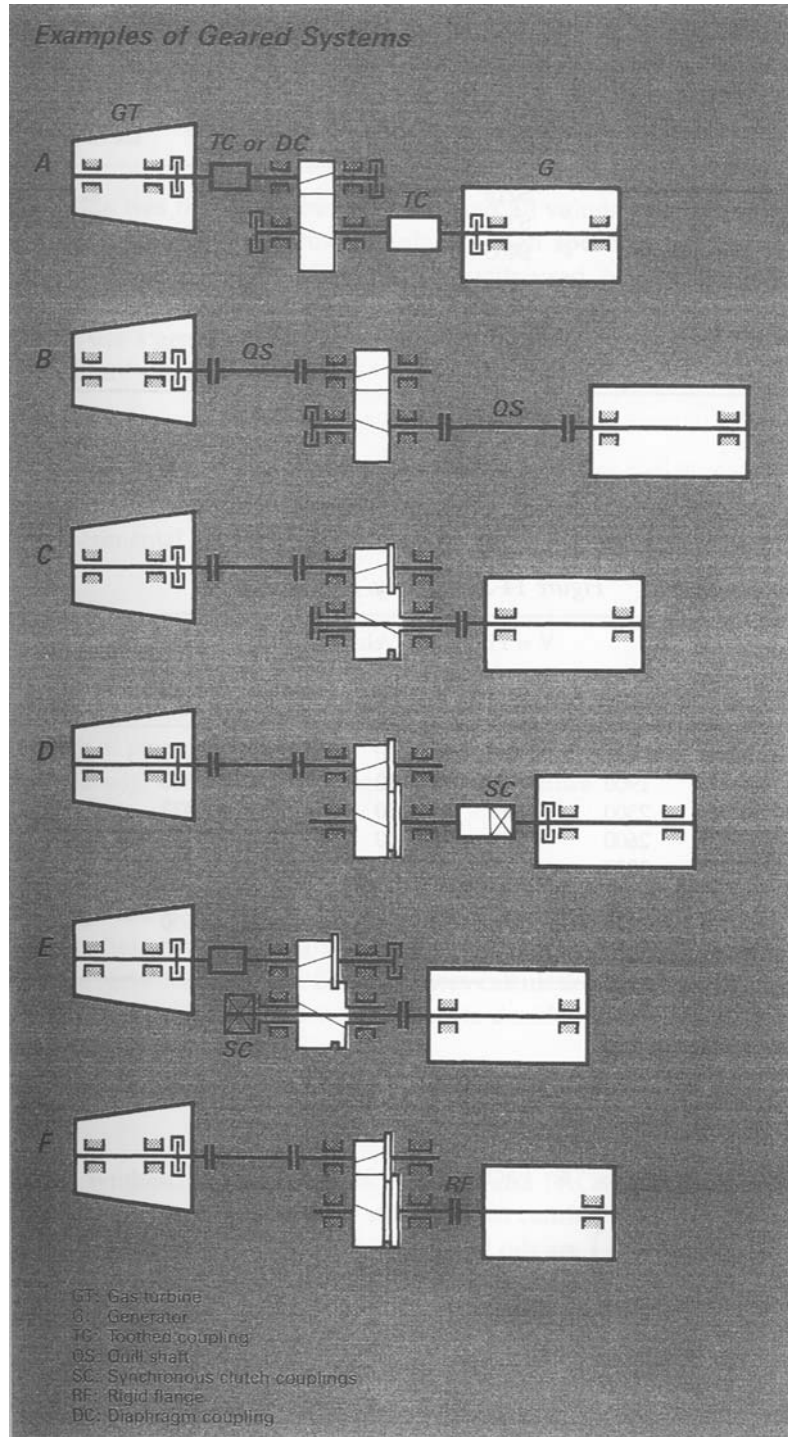

Figure 14-4. Examples of geared systems. (Source: Maag Gear Company, Zurich, Switzerland)

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Table 14-2. Equivalent Viscosities of other systems (for reference only)

AGMA LUBRICANT NO.	EQUIVALENT ASTM-ASLE GRADE NO.	EQUIVALENT ISO GRADE NO.	METRIC EQUIVALENT VISCOSITY RANGES cSt AT 37.8°C (100°F)
1	S215	46	41.4 to 50.6
2, 2 EP	S315	68	61.2 to 74.8
3, 3 EP	S465	100	90 to 110
4, 4 EP	S700	150	135 to 156
5, 5 EP	S1000	220	198 to 242
6, 6 EP	S1500	320	288 to 352
7 comp., 7 EP	S2150	460	414 to 506
8 comp., 8 EP	S3150	680	612 to 748
8A comp.	S4650	1000	900 to 1100

Figure 14-3. Viscosity, SSU @ 100°F.

V = Pitch Line Velocity, FPM

K	50	100	200	500	1000	5000	10000	15000
50	1900	1400	1050	700	500	250	200	175
100	2600	1900	1400	950	700	350	250	225
150	3100	2300	1700	1150	850	425	325	250
200	3500	2600	1900	1300	950	475	350	300
250	3800	2800	2100	1400	1050	525	400	325
300	4100	3100	2300	1500	1150	575	425	350
400	4700	3500	2600	1700	1300	650	475	400
600	5500	4100	3100	2100	1500	750	575	475

$$Vg = 420\,(K/V)^{0.43}$$

Where: Vg = Viscosity, Centistokes
K = Operating "K" Factor

$$K = \frac{W}{dF}\left(\frac{m_G + 1}{m_G}\right)$$

W = Tangential Load
d = Pitch Diameter of Pinion
F = Effective Face Width
m_G = Ratio
V = Pitch Line Velocity, ft./min.

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and:

$$SSU = \frac{Vg + \left(Vg^2 + 158.4\right)^{.5}}{0.44}$$

This formula was first published by Shell, and all values were converted to SSU.

It should be noted that by this formula the high speed gears (above 5000 FPM) require a heavier oil than the 150 SSU @100°F usually used, but compromises are made for bearings and sometimes seals.

We like to use a general rule that for high speed gearing, the minimum viscosity at supply temperature should be 100 SSU.

Film Thickness

Several authorities have stated that film thickness is a function of operating speed only. Based on this theory, the following formula can be used as a guide which was derived from experimental results by Crook and Archard.

$$h_{min} = 0.33d \;\; V_g\left(n_p\right)\left(\frac{m_G}{m_G + 1}\right)^{.5}$$

h = Film thickness (micro-inches)
d = P.D. of pinion
V_g = Viscosity, Centistokes at gear blank temperature
n_p = Pinion speed, RPM
m_G = Ratio

Using this formula, a 5" pinion running with a 20" gear has a film thickness of 385 and 640 microinches at 3,600 and 10,000, respectively, using 100 SSU oil at the mesh.

Due to the variables involved, film thickness calculation procedures are useful only for design comparisons and should not be used to decide that a particular gear set will not work.

Lubricant Types

Mineral Oils

Although synthesized hydrocarbons (diesters and PAOs) are rapidly gaining more wide-spread acceptance, mineral oils are still the most commonly used type of gear lubricant. Containing rust and oxidation inhibitors, these oils are less expensive, readily available, and have very long life. When gear units operate at high enough speed or low enough load intensity, the mineral oil is probably the best selection.

Extreme Pressure Additives

Extreme pressure additives of the lead-napthenate or sulphur-phosphorus type are recommended for gear drives when a higher load capacity lubricant is required. As a general rule, this type of oil should be used in low speed, highly loaded drives, with a

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medium operating temperature.

It should be remembered that EP oils are more expensive and must be replaced more often than straight mineral oils. Some of these oils have a very short life above 160°F temperature.

A good gear EP oil would have a Timken OK load above 60 pounds and pass a minimum of 11 stages of the so-called FZG test.

Boron compounds, as EP additives, are being tested; and these show promise as an extremely high load capacity lubricant. The compounds being tested show Timken OK loads greater than 100 pounds and 14 stages of the FZG test. This additive is nontoxic, highly stable, but sensitive to water.

Synthetic Lubricants

Not to be confused with the highly desirable synthesized hydrocarbons (typically diesters and PAOs), true "synthetic" lubricants are not recommended for general gear applications due to cost, availability, and lack of knowledge of their properties. In extreme applications of high or low temperature and fire protection, they are used. The user must be careful when selecting these lubricants since some of them remove paint and attack rubber seals.

The more recent synthesized hydrocarbons (SHC) have many desirable features such as compatibility with mineral oils and excellent high and low temperature properties. They should be an excellent selection when EP lubricants are required along with high temperature operation. Refer to Chapter 7 for details.

Compounded Oils

Compounded oils are available with many different additives. The most commonly available is a molydenum disulfide compound that has been successfully used in some gear applications. It is difficult for a gear manufacturer to recommend these oils since some of these additives have a tendency to separate from the base stock.

Viscosity Improvers

Viscosity improvers in gear drives should be used with great care. These polymer additives do great textbook things for the viscosity index and extend the operating temperature range of an oil. What must be remembered is that polymers are non-Newtonian fluids, and the viscosity reduces with shearing. A gear drive is a very heavy shear application; and as a result, the viscosity reduces rapidly if too much polymer is used.

Lubricants in gear units have basically two functions: (1) to separate the tooth and bearing surfaces and (2) cooling. On low speed gear units, the primary function is lubrication; on high speed units, the primary function is cooling. This does not mean that both are not important but relates to the relative quantity of oil.

On low speed units, the amount of oil is determined by what is required to keep the surfaces wetted. On high speed units, quantity is generally determined by heat loss (or inefficiency). As a general rule, one GPM must be circulated for each 100 HP transmitted which results in a temperature rise of approximately 25°F. Higher HP units use a 40°F to 50°F temperature rise and require .5 to .6 GPH per 100 HP transmitted. This is based on a 98% efficiency.

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Lubrication of High Speed Units

The oil furnished to high speed gears has a dual purpose: Lubrication of the teeth and bearings, and cooling. Usually, only 10% to 30% of the oil is for lubrication and 70% to 90% is for cooling.

A turbine type oil with rust and oxidation inhibitors is preferred. This oil must be kept clean (filtered to 40 microns maximum, or preferably 25 microns), cooled, and must have the correct viscosity. Synthetic oils should not be used without the manufacturer's approval.

For some reason, the high speed gear makes all the compromises when oil viscosity for a combined lube oil system is determined. Usually a viscosity preferred for compressor seals or bearings is selected and gear life is probably reduced. The bearings in a gear unit can use the lightest oils available, but gear teeth would like a much heavier oil to increase the film thickness between the teeth.

When selecting a high speed gear unit, the possibility of using an AGMA No. 2 Oil (315 SSU @ 100°F) should be considered. In most cases, the sleeve bearings in the system can use this oil and, if not, a compromise 200 SSU at 100°F oil should be considered.

When 150 SSU at 100°F oil is necessary, inlet temperatures should be limited to 110°F to 120°F to maintain an acceptable viscosity. Oil should be supplied in the temperature and pressure range specified by the manufacturer.

Up to a pitch line speed of approximately 15,000 feet per minute, the oil should be sprayed into the out-mesh. This allows maximum cooling time for the gear blanks and applies the oil at the highest temperature area of the gears. Also, a negative pressure is formed when the teeth come out of mesh pulling the oil into the tooth spaces.

Above approximately 15,000 feet per minute, 90% of the oil should be sprayed into the out-mesh and 10% into the in-mesh. This is a safety precaution to assure the amount of oil required for lubrication is available at the mesh.

In addition to the above, in the speed ranges from 25,000 to 40,000 feet per minute, oil should be sprayed on the sides and gap area (on double helical) of the gears to minimize thermal distortion.

Types of Lubrication in Gear Teeth

Boundary Lubrication

Boundary lubrication most often occurs at slow to moderate speeds, on heavily loaded gears, or on gears subject to high shock loads. The oil film is not thick enough to prevent some metal-to-metal contact. This condition usually shows some early wear and pitting due to surface irregularities in the tooth surfaces.

When boundary lubrication is encountered, extreme pressure oils should be used to minimize wear and possible scuffing.

Hydrodynamic Lubrication

Hydrodynamic lubrication occurs when two sliding surfaces develop an oil film thick enough to prevent metal-to-metal contact. This type lubrication usually only exists on higher speed gearing with very little shock loading.

Elastohydrodynamic (EHL) Lubrication

Elastohydrodynamic theory of lubrication is now accepted as very common in gear

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teeth. The formation of EHL films depends on the hydrodynamic properties of the fluid and deformation of the contact zone. This flattening of the contact area under load forms a pocket that traps oil so that the oil does not have time to escape resulting in an increase in oil viscosity. This increase makes possible the use of light oils in high speed drives and usually only occurs above 12,000 FPM.

Methods of Supplying Lubricant

Splash Lubrication

Splash lubrication is the most common and foolproof method of gear lubrication. In this type system, the gear dips and in turn, distributes oil to the pinion and to the bearings. Distribution to the bearings is usually obtained by throw off to an oil gallery or is taken off by oil wipers (or scrapers) which deliver the oil to an oil trough.

Care must be taken that the operating speed is high enough to lift and throw off the oil. In the throw-off system, the minimum speed, n_p, is:

$$n_p = (70{,}440/d)^{.5}$$

Where:

d = Pitch diameter, feet, and
n_p = RPM

Oil wiper systems can operate at much lower speeds which are generally determined by test. The splash system can be used up to 4000 FPM pitch line velocity. Higher speeds can be splash lubricated with special care.

Forced Feed Lubrication

Forced feed lubrication is used on almost all high speed drives and on low speed drives when splash lubrication cannot be used due to gear arrangement.

A simple forced feed system consists of a pump with suction line and supply lines to deliver the oil. However, lubrication supply systems for high speed drives include many of the following components:

- Large reservoir
- Filters (Duplex or Single)
- Shaft driven pump
- Auxiliary Pumps (Motor and Steam)
- Heat exchangers (Single or Duplex)
- Accumulators
- Pressure control devices
- Safety alarms and shutdowns (Temp. and Pressure)
- Temperature Regulators
- Isolation valves
- Heaters (Steam or Electric)
- Purifier (Removes water and oxidation products)
- Flow Indicators

Many of these systems are well designed and constructed for optimum performance.

Scoring or scuffing (adhesive wear) is caused when the oil film does not prevent contact between mating surfaces. Areas touch each other due to load which results in welding of the two surfaces. As sliding continues, these surfaces break apart. These particles adhere to the surfaces, and rapid adhesive wear occurs.

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The flash temperature theory of this type failure indicates that the welding is caused by the high temperature generated locally in the contact area. Calculations can be made to determine the scoring risk for higher speed drives but data are not available for all oil types.

Pitting or surface fatigue comes from the formation of small sub-surface cracks that are developed by fatigue failure of the tooth surface under repeated load. As fatigue failure progresses, the surface begins to break up, and pits form. Pitting usually starts close to the pitch line in the dedendum area.

If a gear is operating above the basic strength of the gear material, no lubricant can prevent pitting. Some pitting is corrective in nature and up to a point, is not detrimental to the gearing. Pitting in case hardened gearing usually leads to failure. Extreme pressure oils and higher viscosity can help reduce pitting.

Abrasive wear is usually caused by a very rough surface finish on the gear teeth or foreign particles in the oil. The foreign particles adhere temporarily to one surface and in turn, scratch a groove in the second surface. Generally, there is very little problem with abrasive wear if the lubricant is clean.

Gear lubrication, at the present time, is not a highly developed technology in general industrial applications and the ultimate capacity of gearing is partially determined by lubricant load limits. Fortunately future higher capacity lubricants (synthesized hydrocarbons) may well solve gear problems by generating thick films without the problems now associated with the extremely heavy oils.

LUBRICATION OF LARGE OPEN GEARS

Large open gears (Figure 14-5) are toothed gear systems, i.e., the gear and the pinion are not situated in a joint housing. The drive cover frequently is not oil-tight. Large

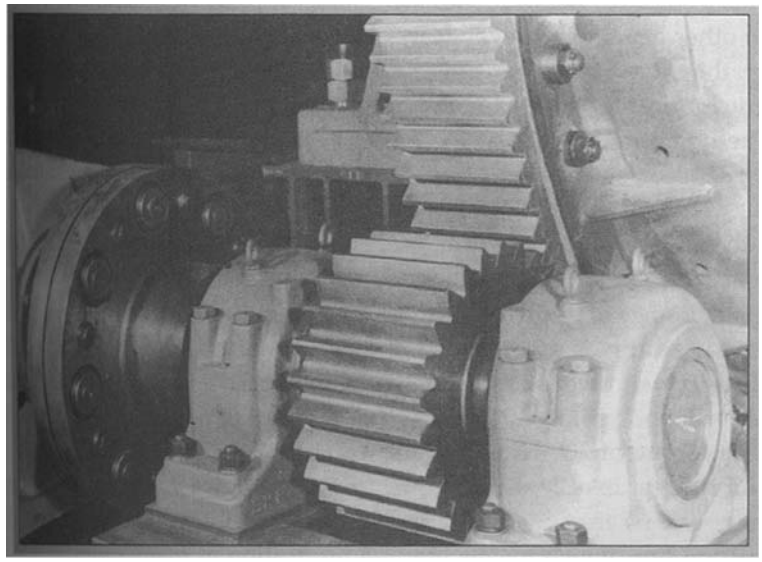

Figure 14-5. Girth gear drive of a drying cylinder.

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open gears are mainly used in the base material industry, for example in ore and raw material processing installations, fertilizer, waste incineration and composting plants, coal-fired plants, rotary kilns, tube mills, drying, cooling and conditioning cylinders.

As the pinion and the gearwheel are supported separately, and owing to the low peripheral speed, extremely high flank load and surface roughness, such gears are mainly operated in the mixed friction regime. To ensure operational reliability it is therefore necessary to apply special adhesive lubricants having specific physical and chemical properties to form a protective layer on the tooth flanks and avoid direct contact between the metal surfaces. Competent vendors often recommend the application of running-in lubricants to rapidly reduce surface roughness when putting the gear into operation and achieve a good load distribution over the flanks and the faces.

One lubricant manufacturer, Klüber, has developed a so-called A-B-C system of lubrication to ensure optimum lubrication during all operating stages and to protect the drive against any damage right from the first assembly-related turns of the gear.

They offer special lubricants tailored to suit any of these steps as well as the various lubricant application methods. Tables 14-4 and 14-5 show the products recommended for the individual step and application method. This lubrication system comprises the following steps:

A = Priming and prestart lubrication
B = Running-in lubrication
C = Operational lubrication

LUBRICATION OF WORM GEARS

Worm gears are of a crossed-axis geometry. They have a constant transmission ratio and are used as speed and torque converters between driving engines and machines. The high sliding percentage of worm gear engagement ensures low-noise and low-vibration operation.

As compared to other gears (e.g., bevel gears), the efficiency of worm gears is relatively poor. However, they make high transmission ratios possible in a single step.

Suitable synthetic lubricants, Table 14-6, reduce the friction and power loss in worm gears up to 30 %. The operational wear of the worm wheels, which usually consist of copper bronze, can be reduced substantially with synthetic lubricants containing suitable additives.

The use of synthetic lubricants in worm gears results in an improvement of the gears' efficiency and service life and makes them suitable for many applications.

Properly formulated special synthetic gear lubricants will not only improve gear efficiency; their anti-wear additives can optimize the gear's wear behavior. Figures 14-6 and 14-7 show the efficiency and wear curves of synthetic Klüber lubricants and mineral hydrocarbon oil. The pertinent worm gear had a center distance of 63 mm, a worm speed of 350 rpm and a drive torque of 300 Nm. (See also Chapter 7.)

The synthetic lubricants' excellent resistance to aging allows extended lubricant change intervals. These can be three to five times longer than intervals recommended with mineral hydrocarbon oils, which means lifetime lubrication in many cases.

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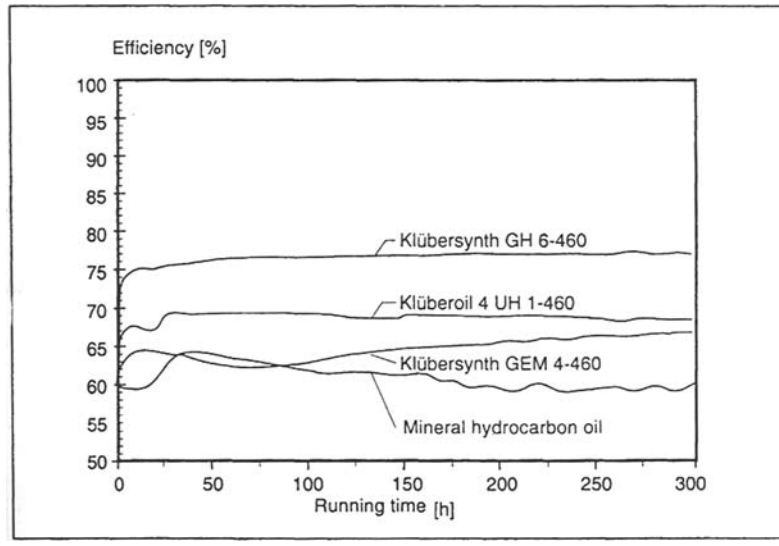

Figure 14-6. Efficiency of mineral hydrocarbon oil compared to synthetic oils.

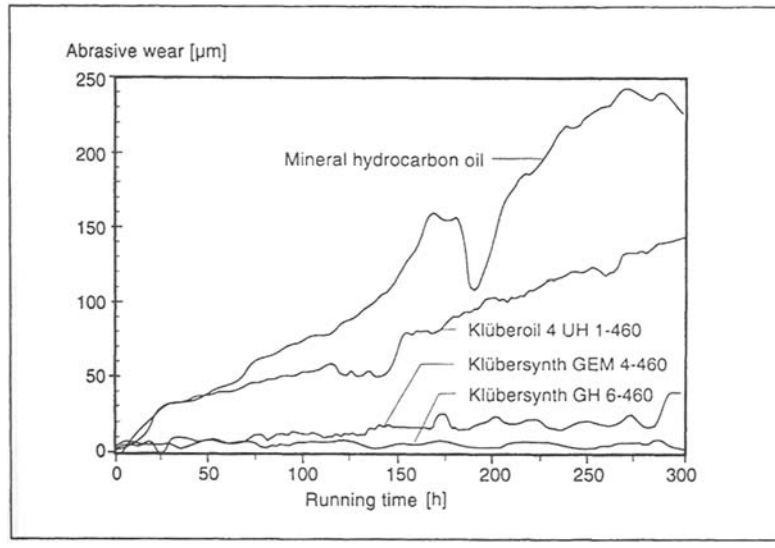

Figure 14-7. Wear curve of mineral hydrocarbon oil compared to synthetic oils.

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LUBRICATION OF SMALL GEARS

Small gears comprise spur, bevel and worm gears of an open, semi-closed or closed design (often not oil-tight).

Small and miniature gears are used in adjusting and control drives in the automotive industry, office machines, household appliances and machines for do-it-yourselfers, Figures 14-8 and 14-9. Their main task is to transfer movements, sometimes also power.

Due to the construction of these gears and the materials that are used—steel/steel, steel/bronze, steel/plastic and plastic/plastic components—the lubricants have to meet various requirements, including

- lifetime lubrication
- noise damping
- low starting torque
- low and high temperature operation
- resistance to ambient media
- compatibility with the materials used

Table 14-4. Lubricant application methods.

Type of lubrication	Type of application	Klüber lubricant						
		A	B		C			
		GRAFLOSCON A-G 1 PLUS	Klüberfluid B-F 1	GRAFLOSCON B-SG 00 PLUS	Klüberfluid C-F 1	Klüberfluid C-F 1	GRAFLOSCON C-SG 0 Plus	GRAFLOSCON C-SG 2000 PLUS
Continuous lubrication	Dip-feed lubrication		•		•	•		
	Lubrication with the Klübematic PA system		•		•	•		
	Dip-feed circulation lubrication		•		•	•		
Long-term lubrication	Transfer lubrication with paddle wheel		•		•	•		
	Transfer lubrication with transfer pinion (plunging into the lubricant)		•		•	•		
Intermittent lubrication	Manual lubrication by brush or spatula	•						
	Manual lubrication with pressurized air spray gun		o	o	o	o	o	o
	Automatic spray lubrication			•	o	o	•	•
Total loss lubrication	Transfer lubrication with pinion (lubricant fed to the pinion by pump)			•	o	o	•	•

• Preferred method
o Possible method

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Table 14-5. Typical products recommended for large open gear drives.

Selection criteria	Product name	Base oil/ thickener	Service temperature range (°C) ≈	Density at 20°C (g/cm³) DIN 51757 ≈	Base oil viscosity DIN 51561 (mm²/s) ≈ 40°C	100°C	Color	Drop point DIN ISO 2176 (°C)	Functional lubricant film	Worked penetration DIN ISO 2137 (0,1mm) 51 818	Consistency NLGI grade DIN	Apparent viscosity KL viscosity grade	Notes
Prestart lubrication priming	GRAF-LOSCON A-G 1 PLUS	Min. hydrocarbon oil/Al complex soap, fine graphite	-15 to 90	1.07	500	31	gray-black	>220	-30 to +200*	310 to 340	1	S	Adhesive lubricant, free from solvents, bitumen and lead
Running-in lubrication, spray lubrication	GRAF-LASCON B-SG 00 PLUS	Min. hydrocarbon oil/ silicate, graphite	-15 to 90	0.99	470	92	gray-black	—	-30 to +200*	400 to 430	00	—	Sprayable adhesive lubricant, free from solvents, bitumen and lead. Scuffing load >12 in the special FZG test A/2/76/50, change in specific weight approx. 12 mg/kWh
Running-in lubrication, dip-feed and circulation lubrication	Klüber-fluid BF-1	Min. hydrocarbon oil/ Al soap, fine graphite	0 to 80	0.99	1300	60	dark brown gray-black	—	-30 to +200*	—	—	—	Running-in lubricant for dip-feed and circulation lubrication, free from solvents, bitumen and lead. Scuffing load >12 in the special FZG test A/2.76/50, change in specific weight approx. 1 mg/kWh
Operational lubrication, spray lubrication	GRAF-LOSCON C-SG 0 PLUS	Min. hydrocarbon oil/Al soap, fine graphite	0 to 90	0.96	680	40	gray-black	>90	-30 to +200*	355 to 385	—	M	Sprayable adhesive lubricant, free from solvents, bitumen and lead. Scuffing load >12 in the special FZG test A/2,76/50, change in specific weight approx. 0.2 mg/kWh.
	GRAF-LOSCON C-SG 2000 Plus	Min. hydrocarbon oil/ Al soap, fine graphite	10 to 90	0.98	1500	60	gray-black	>70	-30 to +200*	400 to 430	00	–	GRAFLOSCON C-SG 2000 plus is particularly suitable for hot climatic conditions
Operational lubrication, dip-feed and circulation	Klüber-fluid CF-1	Min. hydrocarbon oil/ Al soap, fine graphite	-15 to 35	0.96	250	20	dark brown, gray-black	—	-40 to +150*	—	—	—	GRAFLOSCON C-SG 2000 plus Operational lubricant for dip-feed and circulation lubrication, free from solvents, bitumen and lead. Scuffing load >12 in the special FZG test A/2.76/50, change in specific weight approx. 0.2 mg/kWh
	Klüber-fluid CF-2	Min. hydrocarbon oil/Al soap, fine graphite	5 to 100	0.96	3200	94	dark brown, gray-black	—	-30 to +200*	—	—	—	

*Depending on relubrication

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Table 14-6. Typical worm gear lubricants.

Selection criteria	Product name	Base oil/ thickener	Service temperature range (°C)	ISO VG DIN 51 519	Density at 20°C (g/ml) DIN 51757	Kinematic viscosity DIN 51561, (mm²/s) at ≈(VI) 20°C	40°C	100°C	Viscosity index DIN ISO 2909 (°C)	Pour point DIN ISO 3016 (°C) ≈	Flash point DIN ISO 2592 (°C) ≈	Notes
Synthetic gear oils for normal and high temperatures	Klübersynth GH 6-220	Polyglycol oil	-30 to 160	220	1.05	630	220	41	>220	<-30	>300	Scuffing load stage >12 in the special FZG test A/16.6/140; particularly suitable for steel/bronze pairings/ check compatibility with sealing materials and paint coatings
	Klübersynth GH 6-460	Polyglycol oil	-25 to 160	460	1.05	1240	460	79	>240	<-25	>300	
Synthetic gear oils for normal temperatures	Klübersynth GEM 4-220	Synthetic hydrocarbon oil	-40 to 140	220	0.86	627	220	26	>150	<-40	>200	Scuffing load stage >12 in the special FZG test A/16.6/140; also suitable for worm wheels made of aluminum bronze
	Klübersynth GEM 4-460	Synthetic hydrocarbon oil	-30 to 140	460	0.86	1440	460	48	>160	<-35	>200	
Synthetic gear oils for the food-processing industry	Klüberoil 4 UH 1-220	Synthetic hydrocarbon oil	-30 to 110	220	0.85	670	220	33	>170	-35	>200	Scuffing load stage 12 in the FZG test A/8,3/90, DIN 51354 Pt 2; USDA-H1 authorized
	Klüberoil 4 UH 1-460	Synthetic hydrocarbon oil	-30 to 110	460	0.85	1370	460	52	>170	-35	>200	

Selection criteria	Product name	Base oil/ thickener	Service temperature range (°C) ≈	Density at 20°C (g/cm³) DIN 51757 ≈	Base oil viscosity DIN 51561 (mm²/s) ≈ 40°C	100°C	Color	Drop point DIN ISO 2176 (°C)	Speed factor ($n \cdot d_m$) mm•min^{-1} ≈	Worked penetration DIN ISO 2137 (0.1mm)	Consistency NLGI grade DIN 51 818	Apparent viscosity KL viscosity grade	Notes
Fluid synthetic grease for gears that are not oiltight	Klübersynth GE 46-1200	Polyalkyleneglycol oil Li soap	-50 to 120	0.99	120	20	brown	>160	—	400 to 430	00	EL	Scuffing load stage >12 in the FZG test A/8,3/90, DIN 51354 Pt 2

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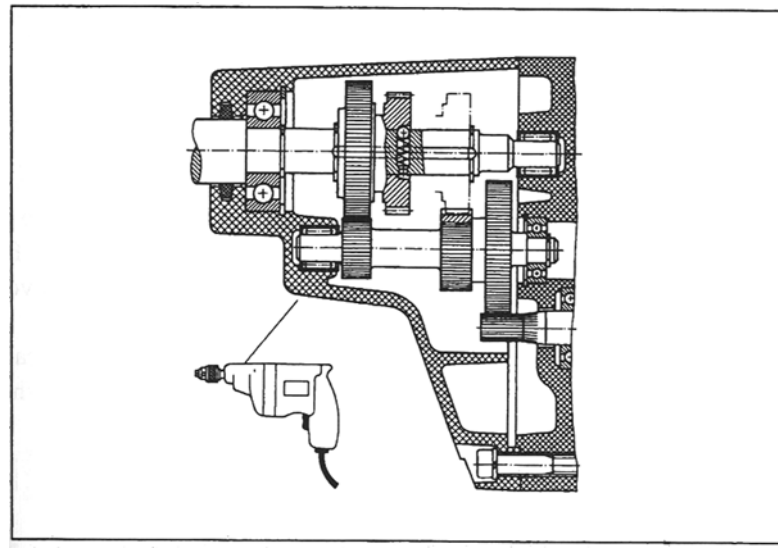

Figure 14-8. Manual drill, double-stage gear.

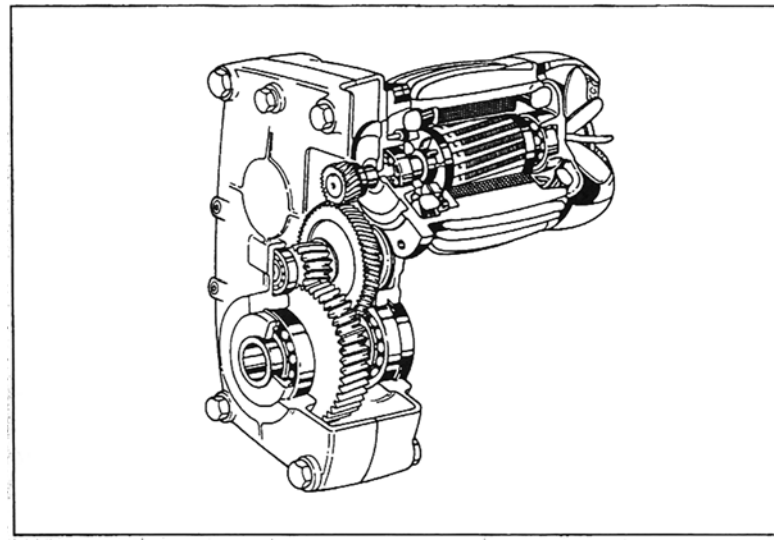

Figure 14-9. Gear motor, double-stage spur gear.

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As small gears often are not oil-tight they are mainly lubricated with greases applied by dip-feed lubrication or one-time lubrication of the tooth flanks.

Dip-feed lubrication is preferred for gears in continuous operation or gears used for power transmission. One-time lubrication is suitable for gears used for the transmission of movements or gears only operating for short intervals or intermittently.

Lubricating greases of NLGI grade 000 to 0 are used for dip-feed lubrication, and of grade 0-2 for lifetime lubrication. To avoid the lubricant being thrown off the gear, pastier greases are preferred in case of increased peripheral speeds. In case of dip-feed lubrication at higher peripheral speeds, however, the grease should be softer to avoid channeling.

Greases with a synthetic base oil are particularly suitable for applications where high resistance to high and low temperatures and aging are required and where the gear friction has to be low. Refer to Table 14-7.

TESTING THE PERFORMANCE OF GEAR OILS

There are three major characteristics a superior EP gear oil should exhibit: extreme pressure capability, cleanliness and demulsibility. In other words, the oil must perform under pressure for extensive time periods, must keep machine systems (and reservoirs) clean and must separate rapidly from water. In developing their SPARTAN EP gear lubricants, Exxon extensively tested for these and other characteristics for two years in order to ensure that the formulation is the best, most dependable lubricant the company could produce with today's leading-edge technology. Such dependability is vital, given the high cost involved in equipment failure and downtime.

Five primary tests run during this two-year period were: EP retention, oxidation, panel coker, copper strip corrosion and demulsibility. The tests measure EP capability, the degree of cleanliness and the demulsibility a lubricant exhibits.

Performance under Pressure

Superior EP lubricants last. They hold up under pressure and over time. They don't have to be replaced as often. That saves money and helps gear units last longer.

The Reserve EP Capability Test measures a lubricant's load-carrying ability over time. EP—extreme pressure—oils are specially formulated to lubricate under heavy-load conditions. The longer a lubricant can maintain its load-carrying ability, the less often it must be replaced...which reduces operating costs.

Before starting this test the specific amount of a key load-carrying ingredient—phosphorus—is measured. Then the lubricant is run through the modified U.S. Steel S-200 Oxidation Test called for in U.S. Steel specification 224. (See the following section on "Superior Oxidation Stability") Once the test is finished the amount of phosphorus is remeasured, to check for any depletion. The more that's left, the more reserve EP capability the lubricant has.

SPARTAN EP gear oil's keep-clean ability helps hold the EP additive in the oil, where the gear can use it—not trapped in the sludge at the bottom of a gear case where it's lost to the gears.

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Table 14-7. Typical small gear lubricants.

Selection criteria	Product name	Base oil/ thickener	Service temperature range (°C) ≈	Density at 20°C (g/cm³) DIN 51757 ≈	Base oil viscosity DIN 51561 (mm²/s) ≈ 40°C	100°C	Color	Drop point DIN ISO 2176 (°C)	Speed factor ($n \cdot d_m$) mm•min⁻¹ ≈	Worked penetration DIN ISO 2137 (0.1mm)	Consistency NLGI grade DIN 51 818	Apparent viscosity KL viscosity grade	Notes
Dip-feed lubrication, normal temperature range	MICRO-LUBE GB 00	Min. hydrocarbon oil/ silicate	0 to 100	0.90	600	38	reddish black	>200	— to +200*	430 to 475	00/000	EL	For gears subject to high loads, scuffing load stage >12 in the special FZG test A/2,76/50
	CENTOPLEX HO	Min. hydrocarbon oil/Li	0 to 100	0.88	110	11.5	beige to brownish almost transparent	>170	5×10^5	370 to 380	0	EL	For low-power small gears
Dip-feed lubrication, low and high temperatures	Klübersynth GE 46-1200	Polyalkylene glycol/Li	-50 to 120	0.99	120	20	brown	>160	—	400 to 430	00	EL	For extreme loads, long-term and lifetime lubrication; scuffing load stage >12 in the FZG test A/8,3/90, Din 51354 Pt 2
	STRUCTOVIS P LIQUID	Polyalkylene glycol/Li	-35 to 130	1.00	365	57	greenish brownish	—	—	600 to 700 (unworked penetration in acc. with Klein at 25°C)	—	EL	Fluid grease for worm gears, long-term and lifetime lubrication
Tooth flank or dip-feed lubrication, normal temperature range	MICRO-LUBE GB 0	Min. hydrocarbon silicate	-0 to 100	0.90	400	25	reddish brown	>180	—	355 to 385	0	L	For gears subject to high loads, scuffing load stage >12 in the special FZG test A/2,76/50
	Klübersynth GE 11-680	Min. hydrocarbon oil/ Al complex	0 to 100	0.94	680	35	brown	>160	—	380 to 420	0/00	L/M	Adhesive lubricant, noise damping, scuffing load stage >12 in the special FZG test A/2.76/50
Tooth flank or dip-feed lubrication, low and high temperatures	Klübersynth G 34-130	Syn. hydrocarb. oil, mineral hydrocarb. oil/special Ca	-30 to 150	0.87	130	16	beige/ brownish	>180	—	355 to 385	0	EL	Lubricant for small gears, e.g., in machines for do-it-yourselfers
	ISOFLEX TOPAS NCA 5051	Synth. hydrocarb. oil/special Ca	-5- to 140	0.80	30	6	beige	>180	1×10^6	385 to 415	0/00	El	Low starting torques, noise damp-with plastic friction components
Tooth flank lubrication	POLY-LUB GLY 801	Synth. hydrocarb. oil, mineral hydrocarb. oil/special Li	-40 to 150	0.88	730	57	beige/	>250	—	310 to 340	1	M	For flank lubrication in case of non-metallic materials, good adhesionand noise damping
	ISOFLEX TOPAS NCA 5051	Synthetic hydrocarbon oil/special Ca	-60 to 130	0.86	18	4	beige	>180	1×10^6	265 to 295	2	L	For plastic/plastic and plastic/ steel components, low starting torque
	ISOFLEX TOPAS NCA 52	Synth. hydrocarb. oil/special Ca	-50 to 150	0.80	30	5.5	beige	>220	1×10^6	265 to 295	2	L	For plastic/plastic and steel/steel components, low starting torque

*Gear relubrication

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SPARTAN EP not only tested better than the competition initially, it tested better in the long run. SPARTAN EP showed very little phosphorus depletion after the modified U.S. Steel S-200 Oxidation Test called for in U.S. Steel specification 224. Table 14-8 presents an overview of a competitive product survey while Table 14-9 lists typical inspections for SPARTAN EP Gear Oils.

Keeping Machine Systems Clean (Figure 14-10)

If a gear oil leaves dirt and sludge in machine systems, it can eventually affect an entire plant's operation. Deposits build in the system, reducing the lubricant's effectiveness, leading to equipment failure...breakdown...or even plant shutdown. SPARTAN EP is designed to minimize these deposits.

When changing to SPARTAN EP it is recommended that contaminants be flushed from the internal gear oil system. Built-up sludge should be removed from centralized system sumps, lines flushed and filters changed. System filters and screens should also be checked during startup and changed if required.

The following tests measured the ability of SPARTAN EP to keep systems clean.

Table 14-8. Gear oil competitive product survey.

Grade	SPARTAN EP 220	Competitor A	B	C	D	E	F	G	H
Kinematic viscosity									
cSt @ 40°C, ASTM D 445	217.5	200.8	206.3	211.0	228.8	208.6	205.1	215.0	215.3
cSt @100°C	18.62	18.11	19.00	18.35	19.39	17.69	18.29	18.19	18.18
Viscosity index	95	98	95	96	96	92	98	92	93
Neutralization number									
ASTM D974	0.44	0.53	0.24	0.83	0.59	0.52	0.48	0.91	0.22
Oxidation stability, USS S-200*									
Viscosity increase									
@ 100°C, %¶	2.3	5.7	1.2	4.9	4.5	7.1	5.8	4.0	7.0
Precipitation number									
Before	nil	nil	nil	nil	nil	nil	nil	nil	nil
After	trace	trace	trace	trace	trace	trace	trace	trace	trace
ER&E analysis of oils after USS S-200†									
Viscosity increase									
@100°C¶	2.9	5.7	0.9	6.2	5.0	6.9	6.8	4.4	7 3
Phosphorous									
depletion loss %¶	2.1	56.0	15.9	3.7	19.2	20.1	15.9	53.4	54.8

*U.S. Steel Lab results.
¶See bar graphs, page 386.
†Exxon Research & Engineering Lab results.

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Table 14-9. Spartan EP typical inspections.

Grade	68	100	150	220	320	460	680	USS	AGMA
ISO viscosity grade	68	100	150	220	320	460	680	—	—
AGMA lubricant number	2EP	3EP	4EP	5EP	6EP	7EP	8EP	—	—
Viscosity:									
cSt @ 40°C, ASTM D 445	68 0	100.0	150.0	220.0	320.0	460.0	680.0	—	—
cSt @ 100°C	8.6	11.1	14.5	18.8	24.0	30.9	41.2	—	—
SSU @ 100°F, ASTM D 2161	353.0	522.0	789.0	1165.0	1705.0	2465.0	3660.0	—	—
SSU @ 210°F	55.0	64.0	78.0	96.0	120.0	151.0	201.0	—	—
Viscosity index	95	95	95	95	95	97	100	95[1]	90[1]
Gravity, ASTM D 287, °API	30.0	29.5	27.8	27.2	26 6	25.7	25 0	25[1]	—
Flash point, ASTM D 92, °C(°F)[2]	210(410)	221(430)	238(460)	243(469)	249(480)	257(495)	257(495)	232(450)	—
Pour point, ASTM D 97, °C(°F)	-21(-6)	-18(0)	-18(0)	-18(0)	-9(16)	-9(16)	-9(16)	-9(16)	—
Timken OK load, ASTM D 2782 kg (lb)	27(60)	27(60)	27(60)	27(60)	27(60)	27(60)	27(60)	27(60)[1]	27(60)[1]
Four-ball EP test, ASTM D 2783									
Load wear index, kg	47	47	47	47	47	47	47	45[1]	—
Weld point,	250	250	250	250	250	250	250	250[1]	—
Four-ball wear test, ASTM D 2266									
Scar diem, mm 20kg, 1800 rpm									
54°C(130°F) 1 hr		0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.35[3]
FZG gear test, minimum stages	12	12	12	12	12	12	12	11	11
Oxidation stability, USS S-200									
312 hr @ 121°C(250°F)									
viscosity @ 99°C(210.F), % increase	2.8	2.7	2.8	2.3	4.0	4.4	4.9	6[3]	10[3,4]
Demulsibility ASTM D 2711									
Water in oil, %	0.3	0,4	0.5	0.8	0.8	1.0	0.9	2.0[3]	1.0[3]
Total free water, ml	85	85	85	85	85	85	85	80[3]	50-60[3]
Emulsion, ml	nil	nil	nil	nil	nil	nil	nil	1[3]	2-4[3]
Foam test, ASTM D 892, ml									
Sequence 1	Tr/0	Tr/0	Tr/0	Tr/0	Tr/0	Tr/0	Tr/0	—	75/10
Sequence 2	Tr/0	Tr/0	Tr/0	Tr/0	Tr/0	Tr/0	Tr/0	—	75/10
Sequence 3	Tr/0	Tr/0	Tr/0	Tr/0	Tr/0	Tr/0	Tr/0	—	75/10
Rust test, ASTM D 665 A/B									
Distilled water	pass	pass	pass	pass	pass	pass	pass	no rust	no rust
Synthetic sea water	pass	pass	pass	pass	pass	pass	pass	no rust	no rust
Copper strip corrosion, ASTM D 130									
3 hr @ 100°C(212°F), rating	1	1	1	1	1	1	1	1B[3]	1B[3]

[1]Minimum
[2]For ISO Grade 68 and 100, 200°C(400°F) is the minimum flash point; ISO 150 and above, 232°C(450°F) is the minimum.
[3]Maximum
[4]ASTM D 2893 95.C(203°F)

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Table 14-9. SPARTAN EP typical inspections (continued)

Grade	1000	1500	2200	3200
ISO viscosity grade	1000	1500	2200	3200
AGMA lubricant number	8A EP	—	—	—
Viscosity:				
cSt @ 40°C, ASTM D 445	940.0	1500.0	2500.0	3200.0
cSt @ 100°C	43.0	54.9	81.0	96.5
SSU @ 100°F, ASTM D 2161	5148.0	6885.0	13,931.0	—
SSU @ 210°F	210.0	260.0	394.0	—
Viscosity index	82	80	80	100
Gravity, ASTM D 287, °API	20.5	20.3	19.7	19.4
Flash point, ASTM D 92, °C(°F)	240(464)	240(464)	243(469)	300(572)
Pour point, ASTM D 97, °C(°F)	-9(16)	0(32)	2(36)	2(36)
Timken OK load, ASTM D 2782, kg(lb)	27(60)	27(60)	23(51)	25(55)
Four-ball EP test ASTM D 2783				
Load wear index, kg	50	50	—	—
Weld point, kg	250	250	250	—
Four-ball wear test, ASTM D 2266				
Scar diam, mm, 20 kg, 1800 rpm, 54°C(130°F), 1 hr	0.3	0.3	0.3	—
FZG gear test, minimum stages	12	12	12	12
Rust test, ASTM D 665 A/B				
Distilled water	pass	pass	pass	pass
Synthetic sea water	pass	pass	pass	pass
Copper strip corrosion, ASTM D 130				
3 hr @ 100°C(212°F) rating	1	1	1	1B

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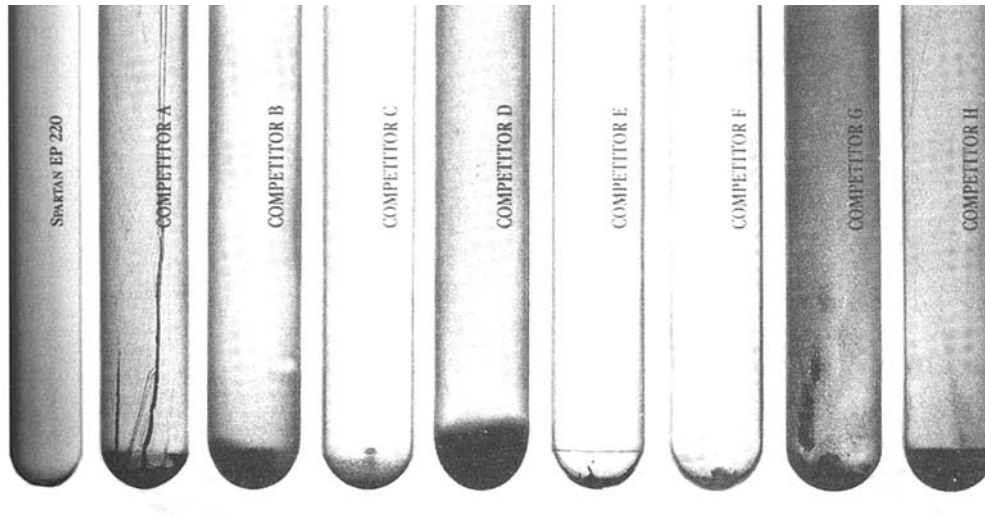

Figure 14-10. SPARTAN EP clearly beats the competition. If most other test tube samples from competitive gear oils look this bad, imagine what their reservoirs must look like after extended service.

Superior Oxidation Stability (Figure 14-11)

All oils in service are exposed to oxidation—a form of deterioration that occurs when oxygen interacts with the oil. Oxidation raises the viscosity of the oil. It also leaves acidic materials which cause the soft sludge deposits or hard, varnish-like coatings. And that can lead to equipment failure. Oxidation stability is particularly important in gear oils that circulate for extended periods at high temperatures.

The primary tests for oxidation are the American Society for Testing and Materials (ASTM) D 2893 and the U.S. Steel S-200 Oxidation Test called for in U.S. Steel specification 224. Both are intended to simulate service conditions on an accelerated basis.

In both ASTM D 2893 and the modified U.S. Steel S-200 Oxidation Test, oil samples are subjected to elevated temperatures in the presence of dry air for 312 hours (13 days). First, oil samples are tested for viscosity at 100°C (212°F) and precipitation number. Then they're poured into test tubes specially fitted with air delivery tubes and flowmeters to ensure an accurate, constant flow of dry air. (The air itself is passed through a drying tower packed with anhydrous calcium sulfate to ensure that it is moisture-free.) The test tubes are immersed in a heating bath and air is bubbled through the oil. The samples are kept at a constant temperature of 95°C(203°F) (in the ASTM D 2893 test) or 121°C(250°F) (in the USS S-200 test) for 312 hours. Test samples are then removed from the bath, mixed thoroughly and tested again for viscosity and precipitation number.

SPARTAN EP controlled the percentage of viscosity increase and—as shown in Figures 14-11 through 14-14—controlled deposits, passing both the ASTM and USS tests with nearly spotless results.

Panels Sparkle with SPARTAN EP (Figure 14-12)

Deposits build up...leading to friction...increased heat...more deposits...increased

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wear and eventual equipment breakdown. The Panel Coker Test measures the effectiveness of a lubricant in keeping the system clean and free from deposits.

This test, which simulates extreme environments, compared SPARTAN EP oil's "keep clean" capability with that of its major competitors. The procedure oil was continuously splashed against metal panels heated to 246°C(475°F) for four hours.

Results are read as the amount of deposits left on the panels. The darker the panels, the more deposits that have been left. The cleaner the panel, the fewer deposits, so the cleaner the lubricant keeps the machine system.

SPARTAN EP kept the panel clean throughout the test.

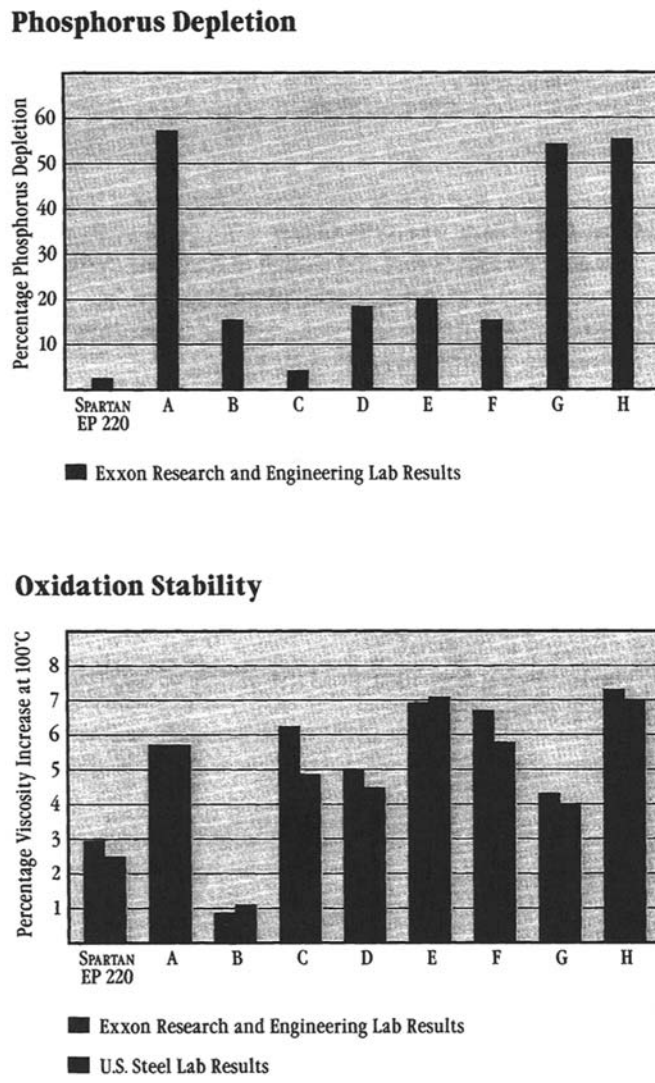

Figure 14-11. SPARTAN EP: low additive depletion results in extended life.

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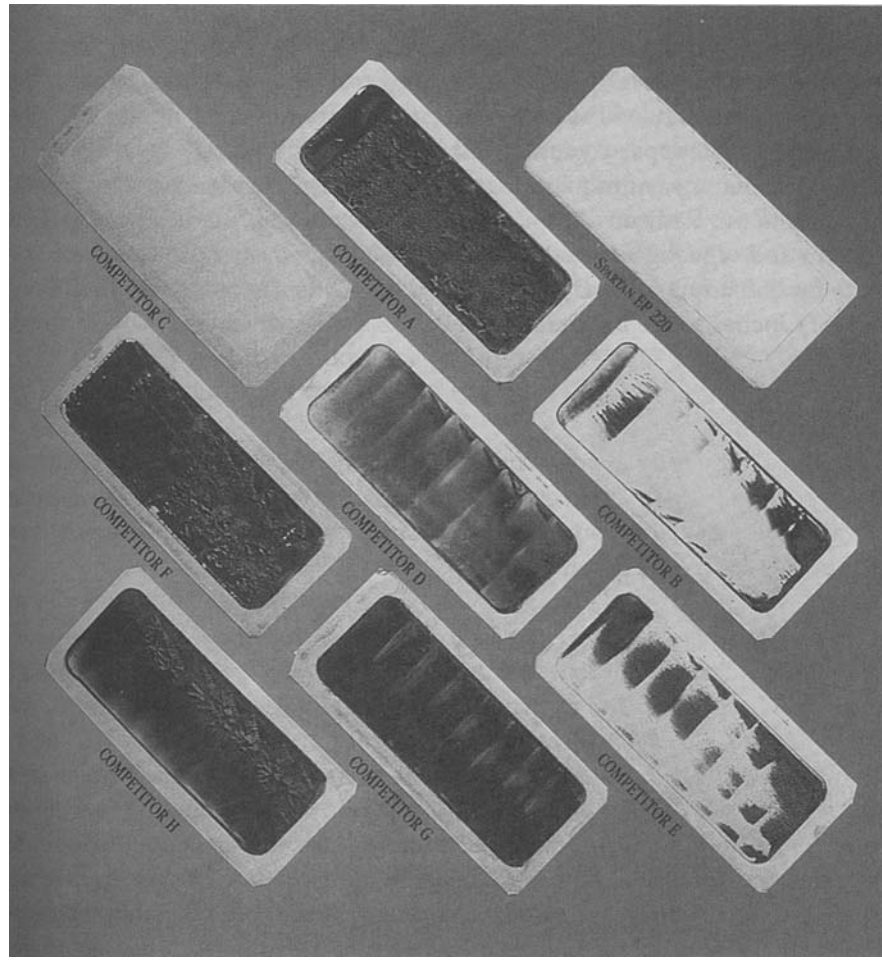

Figure 14-12. SPARTAN EP kept the panel clean, while the competition coked.

No Corrosion Here

Many types of industrial equipment have parts made of copper or bronze. So any oil that comes in contact with these parts must be non-corrosive. With EP oils, chemically active additives are needed to prevent steel-on-steel scoring and seizure. They're indispensable to applications involving steel parts—hypoid gear drives, for example.

The Copper Strip Corrosion Test is used to evaluate the corrosive tendencies of oils to copper and to check them for active sulfur-type EP additives. This test—standardized as ASTM D 130—should not be confused with other tests for the rust-inhibiting properties of petroleum oils, like ASTM D 665. ASTM D 130 evaluates the copper-corrosive tendencies of the oil itself, while other tests evaluate the ability of the oil to prevent ferrous corrosion.

During the standard ASTM D 130 test, special three-inch copper strips are cleaned and polished. For materials of low volatility, the strip is immediately immersed in a test tube of oil and covered with a vented stopper. The tube is held in a water bath for three

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hours at a temperature of 100°C(212°F). At the end of the exposure period, the strip is removed and the oil wiped off. It's compared to a specially prepared set of standardized reference strips that illustrate from Class 1 (slight tarnish) to Class 4 (heavy tarnish). Results are reported as an ASTM D 130 rating. All seven of the lighter ISO grades of SPARTAN EP passed the copper corrosion test with a Class 1 rating.

Another test that measures a lubricant's corrosiveness tendencies to copper-containing compounds is the Radicon Worm Gear Test. In this test, the lubricant is applied to Radicon worm and wheel gears and the clearance between them is measured. The gears are then run for 250 hours at 90°C(194°F), and the end clearance is measured. SPARTAN EP measured 0.011 inches at the beginning and 0.0123 inches at the end, which translates as excellent results.

Excellent Demulsibility

Gear oils are frequently exposed to water, from damaged coolers, lines, atmospheric moisture or occasional steam sources. Water speeds the rusting of ferrous machine parts and accelerates the oil's oxidation. So a gear oil must have good demulsibility characteristics for quick, effective water removal.

SPARTAN EP and Water Don't Mix (Figure 14-13)

A high-quality gear oil resists emulsification and will separate rapidly and thoroughly from water. The test for measuring demulsibility characteristics for EP oils has been standardized as ASTM D 2711.

In this test a 360-ml sample of oil and a 90-ml sample of distilled water are vigorously stirred together for five minutes in a special graduated separating funnel, with the temperature maintained at 82°C(180°F). After a 5-hour settling period, a 50-ml sample drawn from near the top of the oil layer is centrifuged to determine the "percent water in the oil." 'Milliliters of free water" is also measured and reported. Then the mixture is siphoned off until only 100 ml remain in the bottom of the funnel. This is centrifuged and the milliliters of water and emulsion are reported. This amount of water is added to the amount of free water determined in the first separation step above, and the sum is reported as "total water."

SPARTAN EP satisfied both AGMA and U.S. Steel specification requirements in all three steps. These oils represent a multi-industry tool, effective in operating temperatures up to 93°C(200°F). From docks to oil fields, steel mills to paper mills, mines to rolling mills, textile plants to sugar mills, SPARTAN EP keeps the gears turning and plants operating in a wide variety of industries.

High-Temperature, Heavy-Duty Power for the Steel Mills

Modern steelmakers need a lubricant that performs under high temperatures and exhibits excellent demulsibility. SPARTAN EP is designed for the heavy-duty, high-temperature applications found in steel mills. It demonstrates a high level of load-carrying performance—determined in both extreme-pressure and anti-wear tests—and its keep-clean ability helps reduce deposits. It also protects against rust and oxidation, and provides a high level of water shedding and anti-foaming characteristics.

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High Viscosity Index Means Effective Marine Use (Figure 14-14)

A gear oil used in a marine environment must perform in a wide range of temperatures and conditions. Without this capability, at high temperatures the oil's viscosity may drop to a point where the lubricating film is broken...and that means metal-to-metal contact and severe wear. At the other extreme, the oil may become too viscous for proper circulation, or may set up such high viscous forces that proper operation of machinery is difficult. SPARTAN EP has a high viscosity index—ideal for marine applications.

And of course, lubes used in a marine environment will be exposed to water. As the Demulsibility Test demonstrates, SPARTAN EP separates rapidly and thoroughly from water. Its superior demulsibility characteristics mean quick, effective water removal. Additionally, SPARTAN EP exhibits excellent anti-rust properties in the presence of sea water.

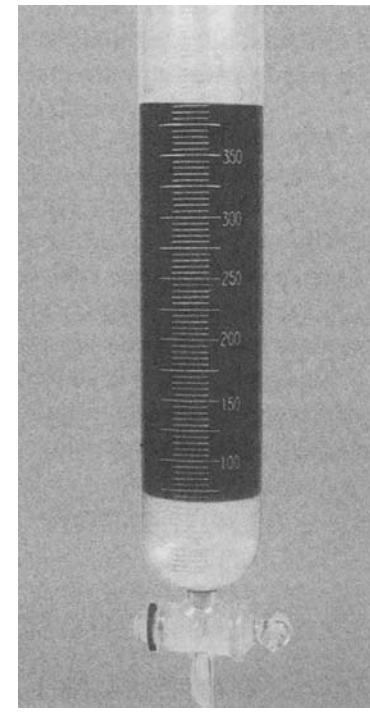
SPARTAN EP is also recommended for use in the deck equipment of motorships, including capstans, winches and windlasses.

Protection for Pulp and Paper Applications

From harvesting and transporting wood to producing lumber, pulp and paper, the forest products industry needs a lubricant designed to minimize equipment downtime and ensure maximum productivity.

And, like steel mill machinery, pulp and paper mill machinery requires a lubricant that performs well under high temperatures and exhibits excellent demulsibility. Good protection under severe load conditions and protection against welding and scoring of gear components are needed.

Spartan EP oil's excellent rust protection is a big plus in the humid paper mill environment. It repre-



ABOVE: Figure 14-13. SPARTAN EP separates rapidly from water.

LEFT: Figure 14-14. SPARTAN EP has the high viscosity index needed for demanding marine applications.

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sents an effective lubricant for forest and woodyard equipment such as conveyors, and for pulp and paper mill equipment such as paper machines, gear drives, vacuum pump gear cases and vibrating screen gear cases. The high cost of this machinery necessitates a lubricant that maximizes yield and helps ensure reliable equipment performance.

Applications Above and Below Ground in Mining Use

Mining costs continue to rise. Mining machines are being pushed to the limits of their capabilities in order to maximize tonnage and increase efficiencies. Productivity is a must. As a result, typical operating temperatures and pressures are significantly higher than in the past. These demanding circumstances require a proven performer under severe operating conditions.

SPARTAN EP provides the superior performance properties demanded by increasingly sophisticated mining machinery and techniques.

Maximum Equipment Life for Aluminum Rolling Industry (Figure 14-15)

The use of aluminum containers for beverages continues to grow. It's the preferred container among brewers, bottlers and distributors—compact, easily adaptable to high-speed filling lines and lightweight. And that makes handling and transportation easier. Its high recycling value is also a major factor in its favor. Cans are currently the most popular single-service soft drink containers, while beer manufacturers continue to switch from glass containers to aluminum.

Nonetheless, this is a highly competitive market and every aluminum manufacturer must continually focus on mill reliability and productivity.

That's where an oil with superior EP capabilities and high viscosity index can save mills money in equipment maintenance and turnover. SPARTAN EP is recommended in roll stands and gear boxes throughout aluminum cold rolling mills.

GEAR COUPLING LUBRICATION

If a user elects to use grid or gear couplings instead of nonlubricated coupling types, he should be made aware of their vulnerability. The gear coupling, Figures 14-16

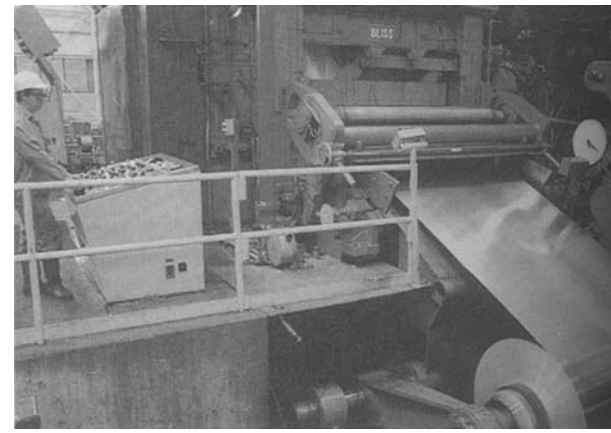

Figure 14-15. Saving money in equipment maintenance and turn- over is a high priority for today's aluminum rollers—so they can rely on SPARTAN EP.

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and 14-17, is one of the most critical components in a turbomachine and requires special consideration from the standpoint of lubrication.

There are two basic methods of gear coupling lubrication: batch and continuous flow. In the batch method the coupling is either filled with grease or oil; the continuous flow type (Figure 14-17) uses only oil, generally light oil from the circulating oil system.

The grease-filled coupling requires special quality grease. The importance of selecting the best quality grease cannot be overemphasized. A good coupling grease must prevent wear of the mating teeth in a sliding load environment and resist separation at high speeds. It is not uncommon for centrifugal forces on the grease in the coupling to exceed 8,000 Gs.

Testing of many greases in high speed laboratory centrifuges proved a decided difference existed between good quality grease and inferior quality grease for coupling service. Testing also showed separation of oil and soap to be a function of G level and time. In other words, oil separation can occur at a lower centrifugal force if given enough time. The characteristics of grease that allow the grease to resist separation are high viscosity oil (Figure 14-18), low soap content, and soap thickener and base oil as near the same density as possible. In the late 1970's, a number of greases were tested for separation characteristics in a Sharpies high speed centrifuge and for wear resistance on a Shell 4 Ball Extreme Pressure Tester. It was found (Table 14-10), that Grease B exceeded all other greases tested in separation characteristics. Zero separation was recorded at all speeds up to and including 60,000 Gs. Greases A, C, and D were rated poor in separation characteristics at all speeds tested.

Table 14-11 illustrates how these four greases performed on the Shell 4 Ball Extreme Pressure Tester in comparison with a typical Extreme Pressure gear oil. Based on these data, Greases A and B should provide excellent wear protection in severely loaded service. However, only Grease B passes the oil separation test and would qualify for long-term service at a modern facility.

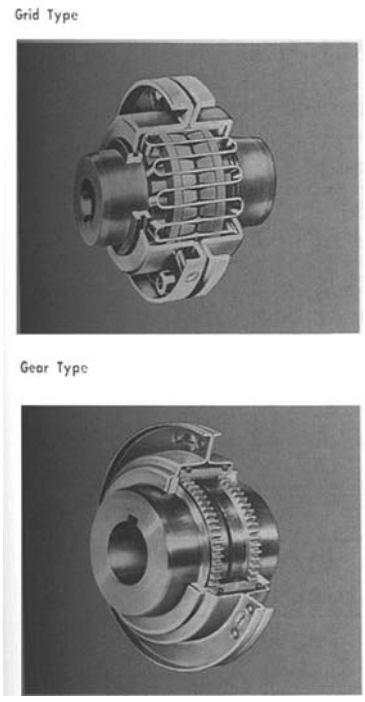

Figure 14-16. Typical couplings requiring grease lubrication.

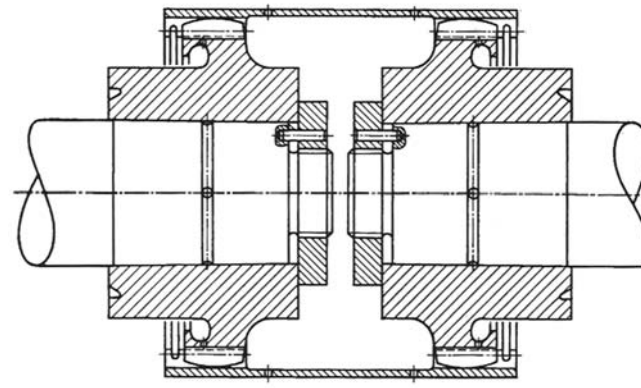

Figure 14-17. Section through a tooth-type coupling. (Source: ASEA Brown-Boveri, Baden, Switzerland)

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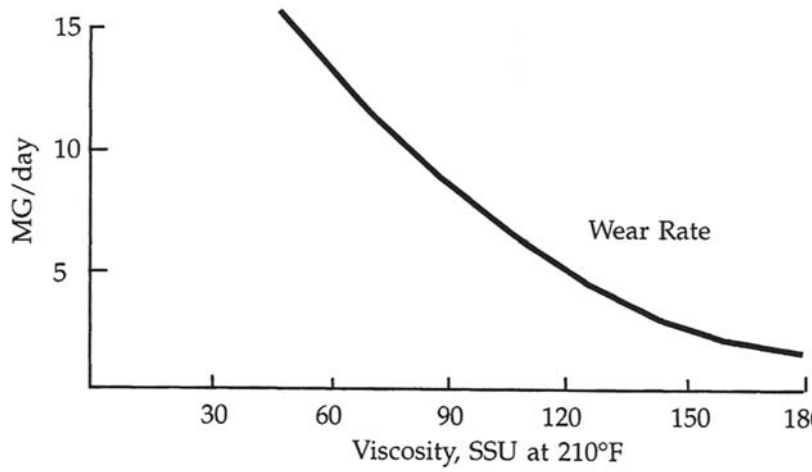

Figure 14-18. Viscosity vs. wear plot.

Refer to Table 14-12 for typical inspections on Exxon's HIGH SPEED COUPLING GREASE, reflecting the testing practices of 1997 and 1998. This high-quality grease was formulated to lubricate all flexible couplings. In particular, it meets the lubrication needs of couplings operating at high speeds and with high centrifugal forces. It provides extreme-pressure protection and is suitable for operating temperatures between -40°C (-40°F) and 149°C(300°F). EXXON HI-SPEED COUPLING GREASE offers excellent resistance to oil separation, as indicated by ASTM D 4425 test results (K36 typically <4/24).

Table 14-10. Oil separation (%) observed on four coupling greases.

	"G" Level		
GREASE	60,000 2.5 hr	32,000 6 hr	9,700 6 hr
GREASE "A"	53	35	—
GREASE "B"	0	0	0
GREASE "C "	79	75	40
GREASE "D"	51	—	—

Table 14-11. Shell 4 ball test—one minute wear load performance of four coupling greases.

GREASE	KILOGRAM LOAD PASSED
GREASE "A"	80
GREASE "B"	90
GREASE "C "	50
GREASE "D"	20
TYPICAL E.P. 140 OIL	90

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HIGH SPEED COUPLING GREASE utilizes a state-of-the-art calcium sulfonate thickener system. This thickener system has several unique performance advantages over conventional lithium-polymer thickener systems used in many competitive coupling greases. Some of the performance benefits of the calcium sulfonate thickener are:

- Excellent corrosion prevention, even in the presence of salt mist
- Inherent EP and anti-wear protection
- High dropping points
- Superior oxidation resistance
- Excellent shear stability

Table 14-12. Typical inspections for Exxon's HIGH-SPEED COUPLING GREASE.

Soap type	Calcium Sulfonate
NLGI grade	1
Appearance	Light brown or tan
Dropping point, ASTM D 2265, °C (°F)	>260 (>500)
Penetration ASTM D 217, mm/10, worked 60 ×	320
Timken OK load, ASTM D 2509, lb	60
Four Ball EP, ASTM D 2596	
LWI, kg	62
Weld point, kg	500
Base oil viscosity, ASTM D 445	
cSt @ 40°C	329
cSt @ 100°C	22.5
Rust test, ASTM D 1743	Pass
Water washout, ASTM D 1264, 79°C, % loss	2.5
Centrifugal separation,	
K36 = % oil separated/test hours, ASTM D 4425	K36 <4/24

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